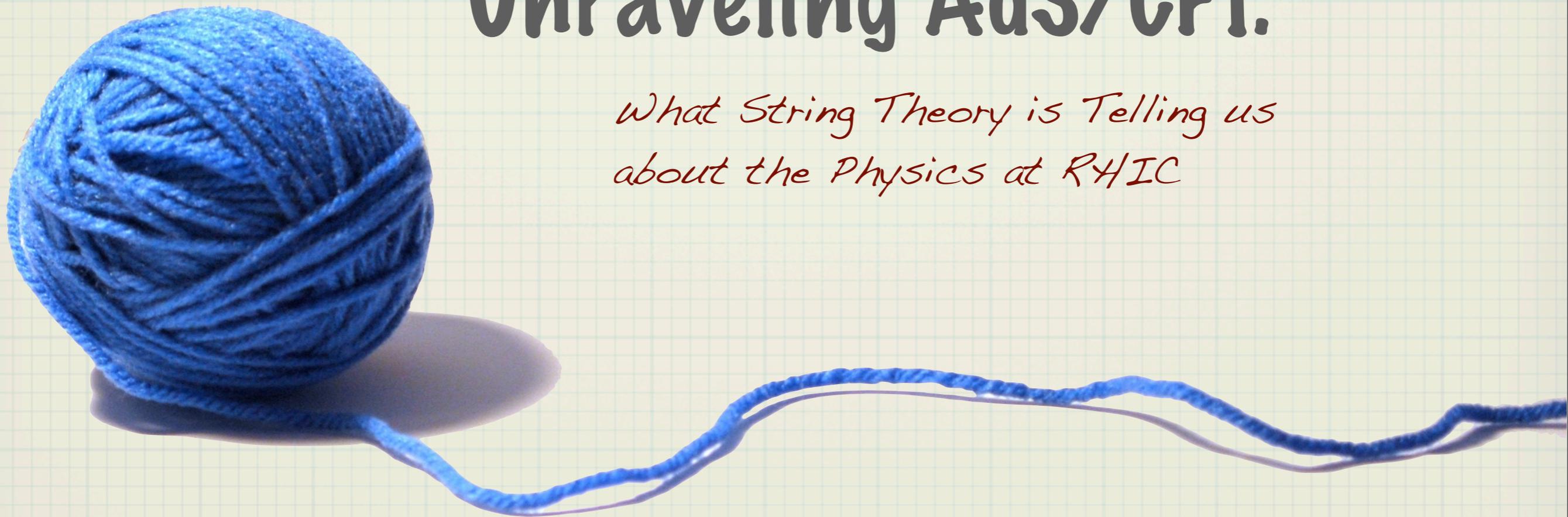


# Unraveling AdS/CFT:

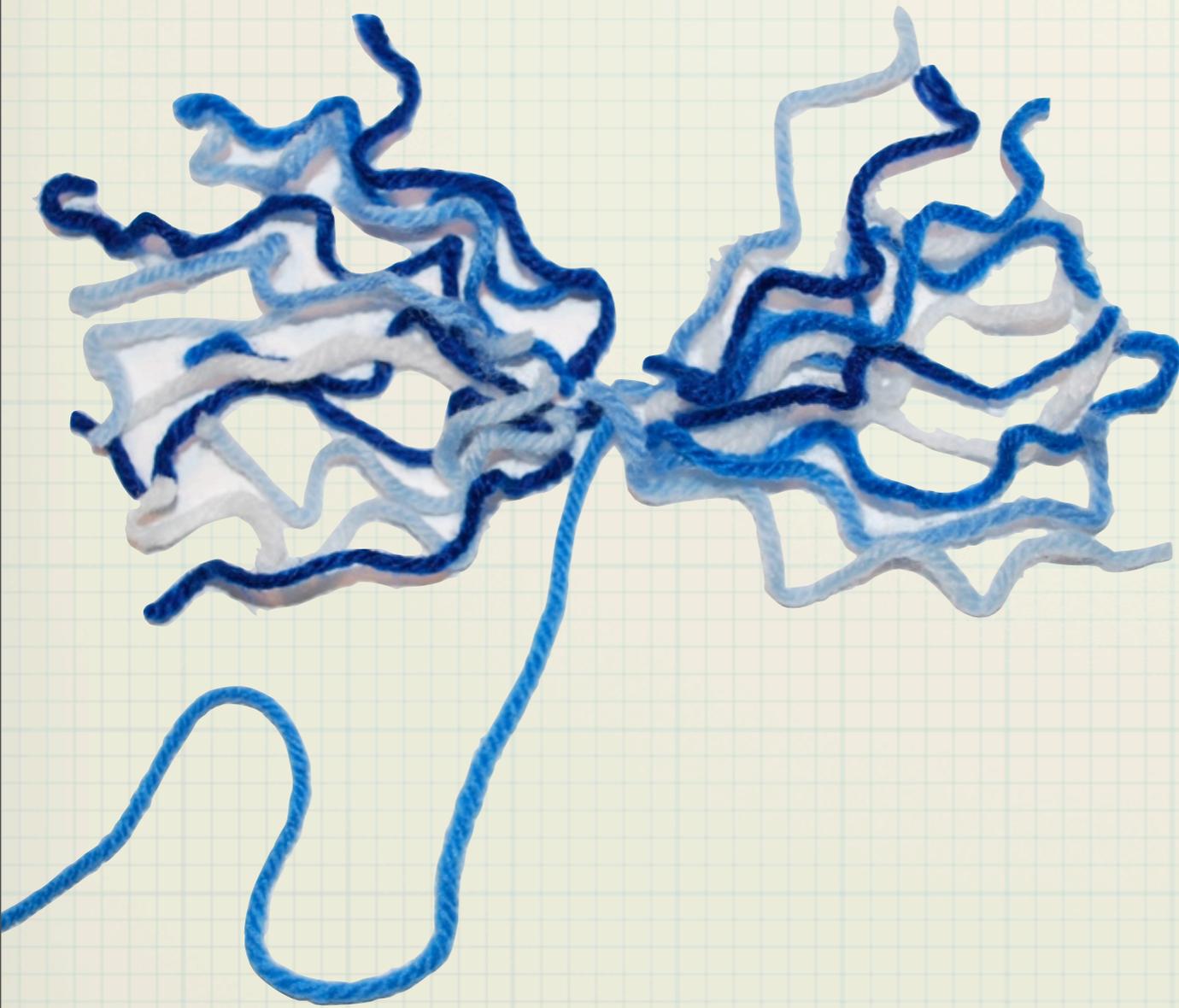
*What String Theory is Telling us  
about the Physics at RHIC*



**Chris Rosen**  
University of Colorado, Boulder

# The Order of Events

Some things RHIC physicists should know about strings

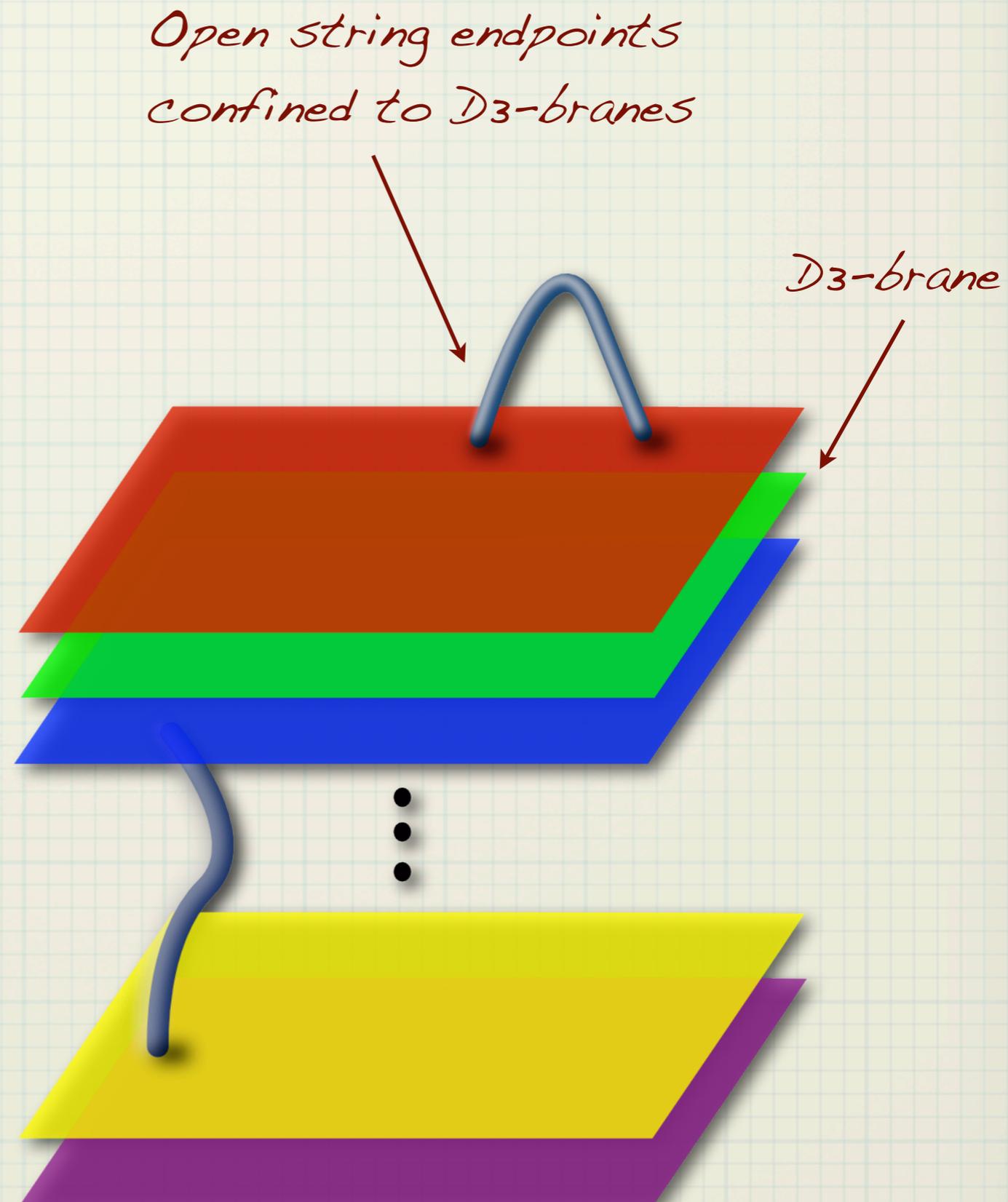


- What is this correspondence and how does it work?
- How can we use it to study the hot dense matter at RHIC?
- Why should I believe anything a string theorist tells me?
- What's next?

# The Way Things Work

The world volume of a stack of D3-branes supports a gauge theory

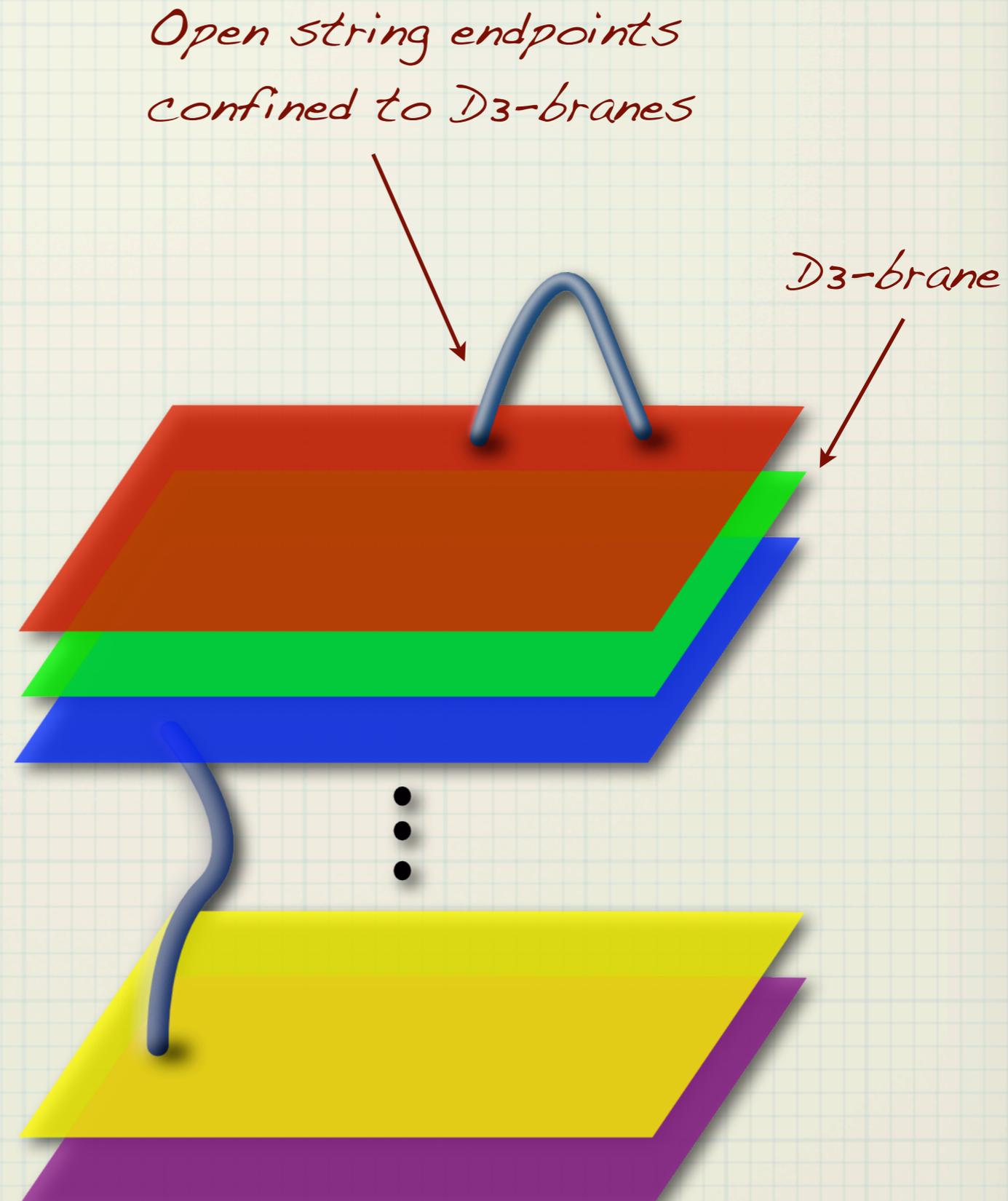
- The  $N_c^2 \rightarrow SU(N_c)$  SYM theory in 3+1 dimensions.



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- Revisit t'Hooft.
- For large  $N_c$ , stack is heavy!

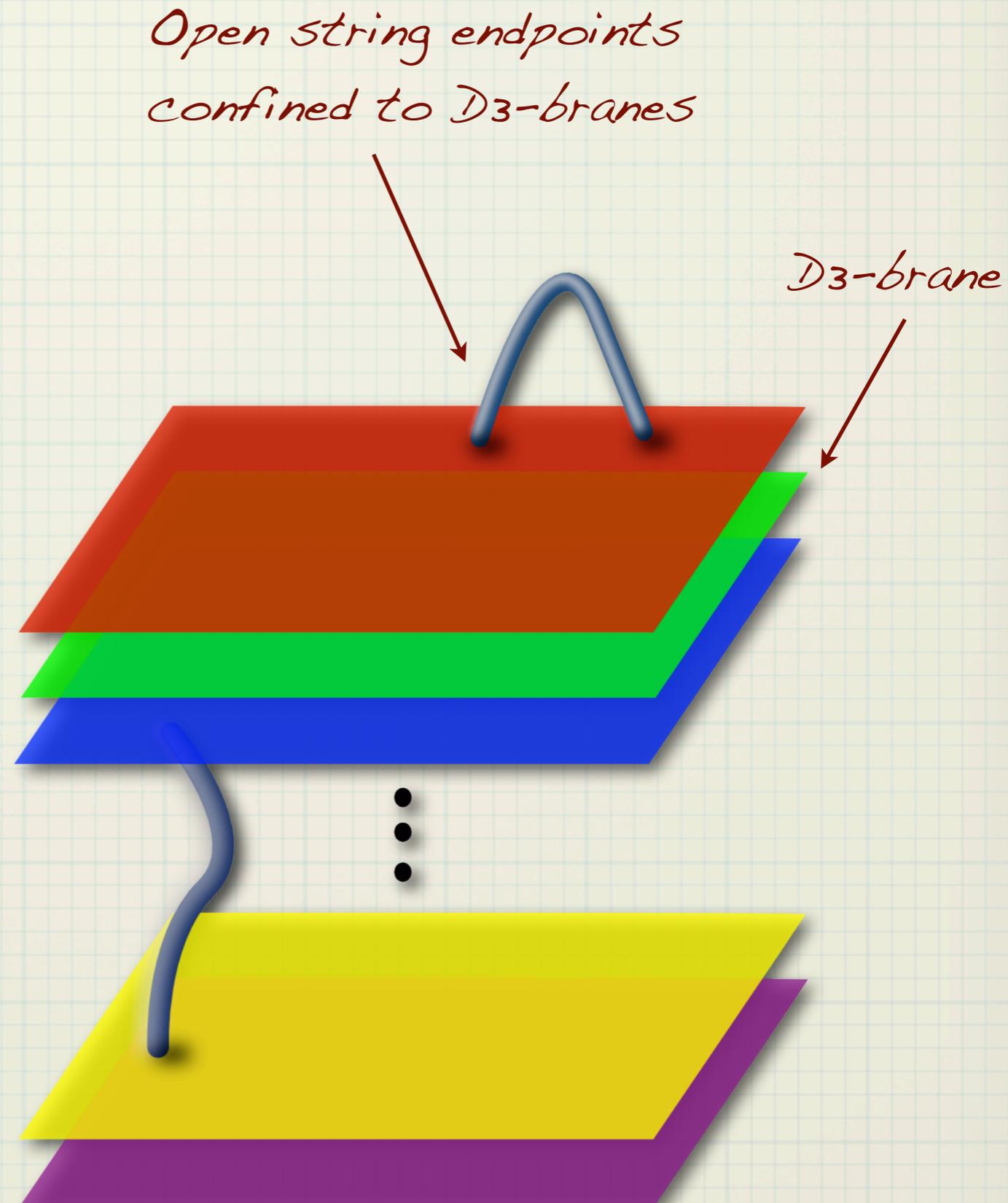


# The Way Things Work

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- The  $N_c^2 \rightarrow SU(N_c)$  SYM theory in 3+1 dimensions.
- Revisit t'Hooft.
- For large  $N_c$ , stack is heavy!
- Insight of AdS/CFT: dictionary should exist.

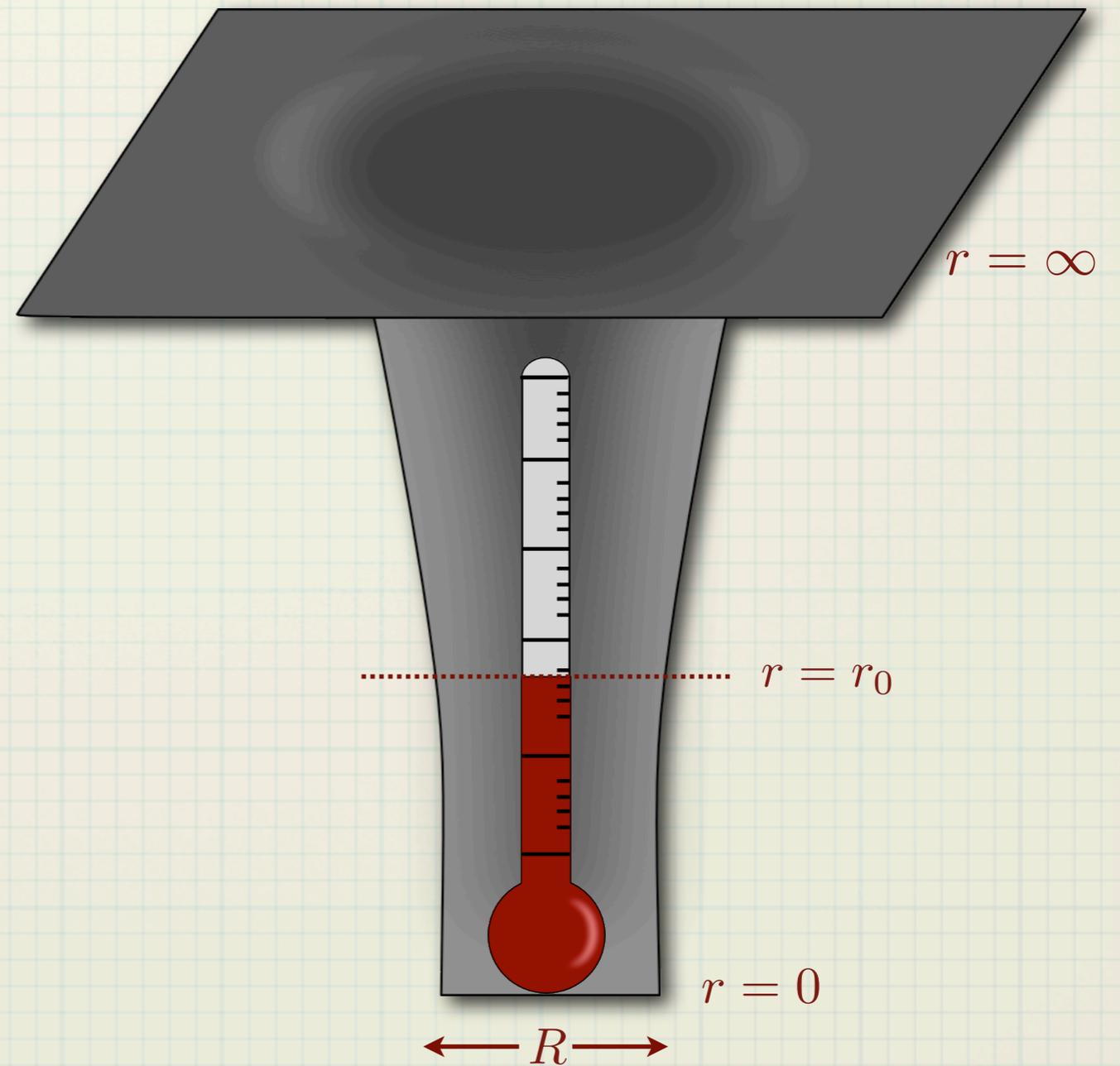
Learn about the CFT by studying the AdS



# The Way Things Work

Strongly coupled gauge theory in  $d = 3+1$   
is described by SUGRA in  $d = 9+1$

- What spacetime looks like hot QCD?
- Should have a temperature, entropy, hydrodynamics, no SUSY...



# The Way Things Work

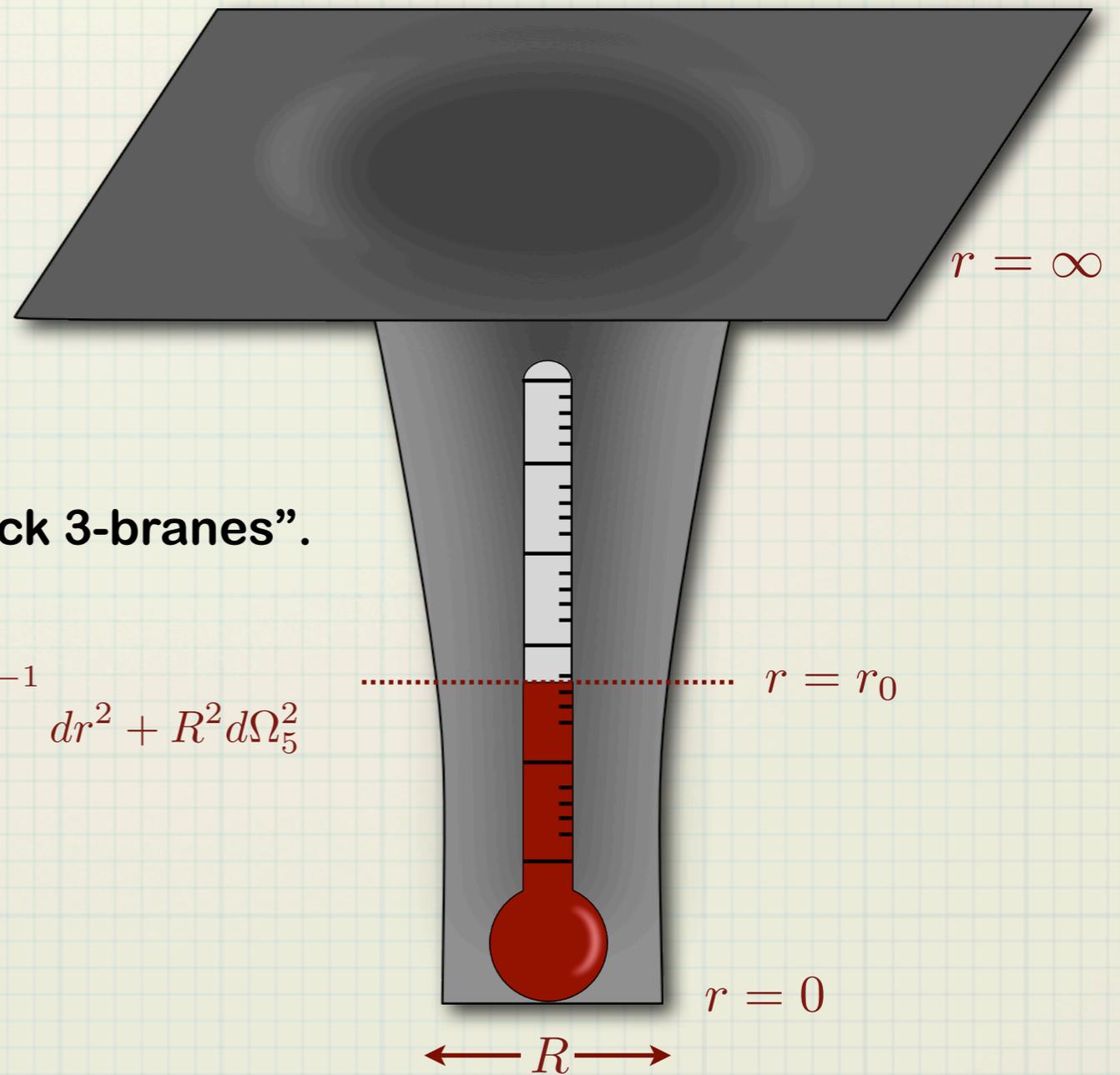
Strongly coupled gauge theory in  $d = 3+1$   
is described by SUGRA in  $d = 9+1$

- What spacetime looks like hot QCD?
- Should have a temperature, entropy, hydrodynamics, no SUSY...
- ...like a black hole! --> “near extremal black 3-branes”.

$$ds^2 = \frac{r^2}{R^2} \left[ - \left( 1 - \frac{r_0^4}{r^4} \right) dt^2 + d\vec{x}^2 \right] + \frac{R^2}{r^2} \left( 1 - \frac{r_0^4}{r^4} \right)^{-1} dr^2 + R^2 d\Omega_5^2$$

- Hawking temperature corresponds to temperature of field theory.

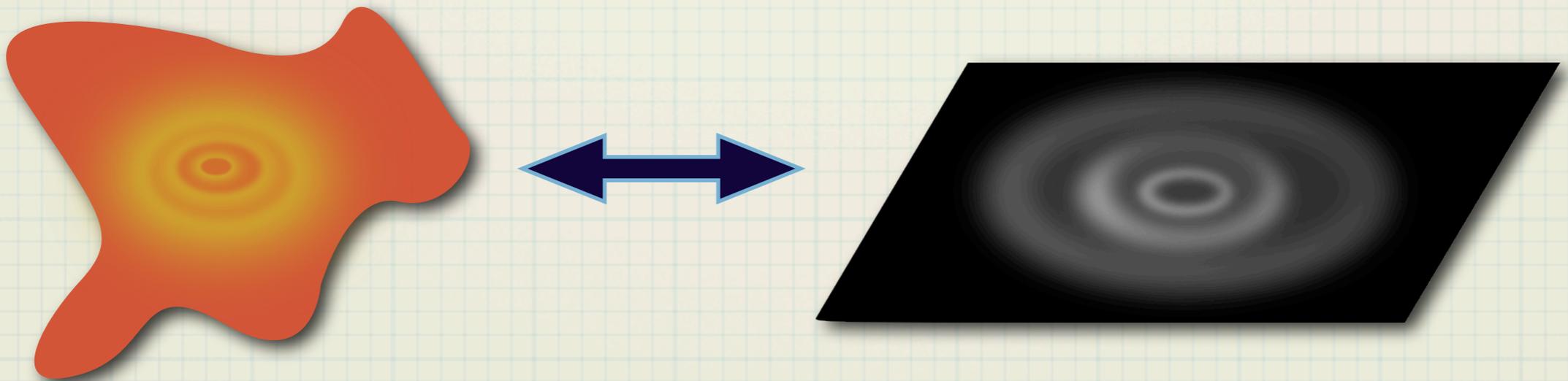
$$T = \frac{r_0}{\pi R^2}$$



# The Way They Generalize

Universality encourages contact with  
RHIC physics

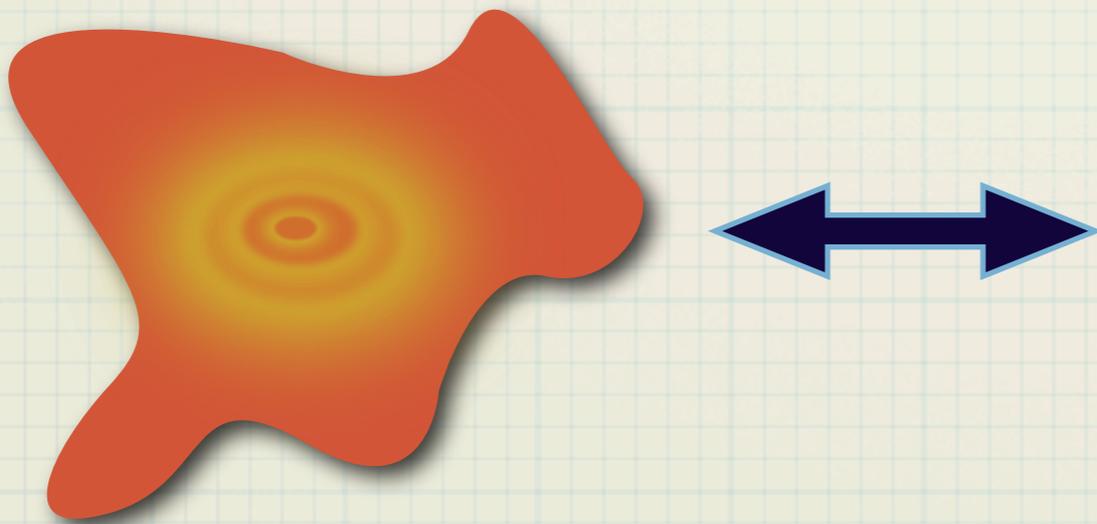
- AdS/CFT results are in principle model dependent. If we don't know QCD dual, how trustworthy are calculations?
- A familiar example: Generic properties of black branes suggest universality of  $\eta/s$ ...



# The Way They Generalize

Universality encourages contact with  
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- AdS/CFT results are in principle model dependent. If we don't know QCD dual, how trustworthy are calculations?
- A familiar example: Generic properties of black branes suggest universality of  $\eta/s$ ...



- Details can be filled in with e.g. Kubo formulas

*black brane dissipation related  
to absorption cross section*

$$\eta = C_\eta \cdot \sigma_A = C_\eta A_H$$

$$s = C_s \cdot A_H$$

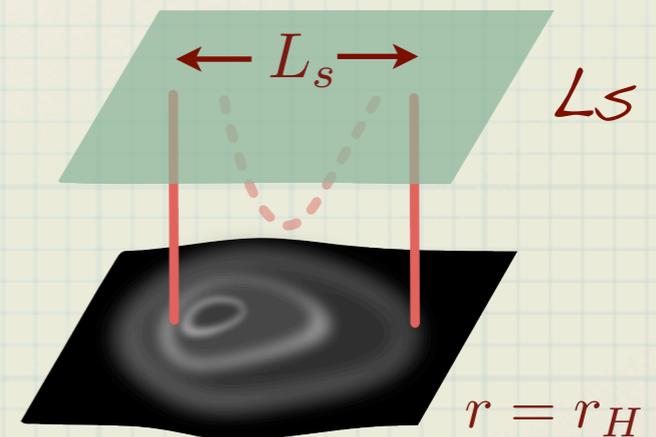
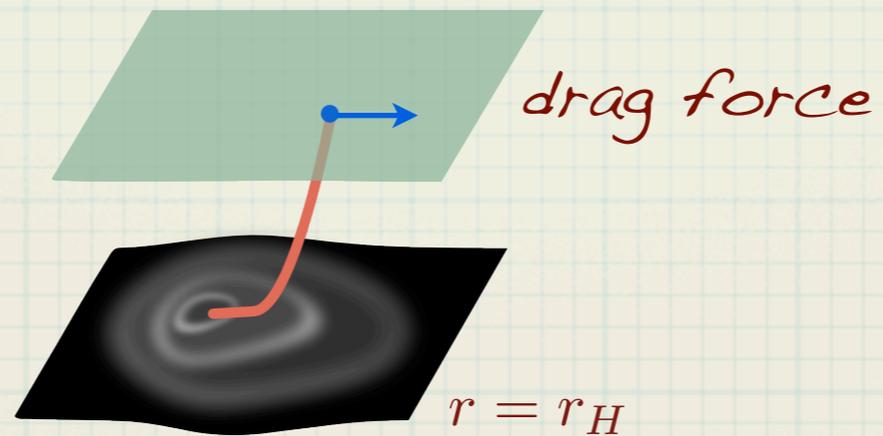
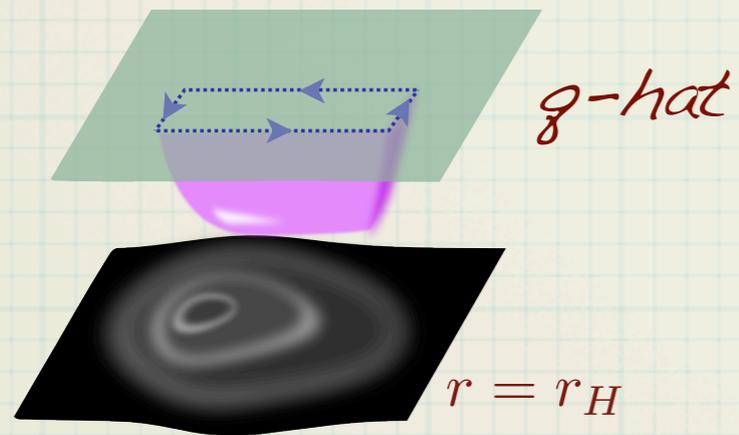
$$\frac{\eta}{s} = \frac{C_\eta}{C_s} = \frac{1}{4\pi}$$

*has been checked for many  
geometries!*

# The Way They Don't

Without universality, proceed with caution

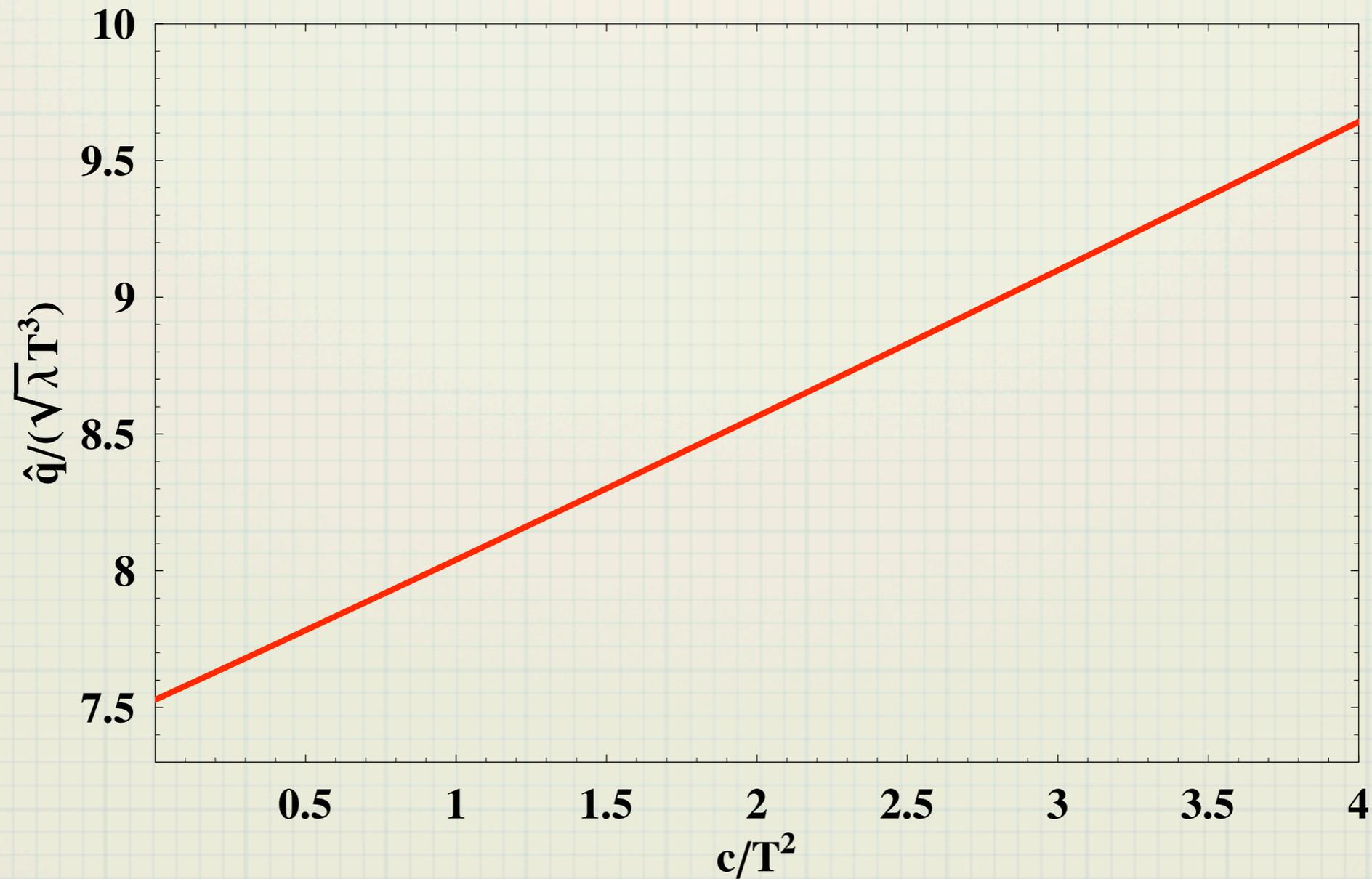
- Many other calculations from AdS/CFT have been applied to RHIC physics...



# The Way They Don't

Without universality, proceed with caution

- ...are they 'good' descriptions of QCD physics?  
(H.Liu, K. Rajagopal, Y.Shi arxiv:0803.3214v2 [hep-ph])

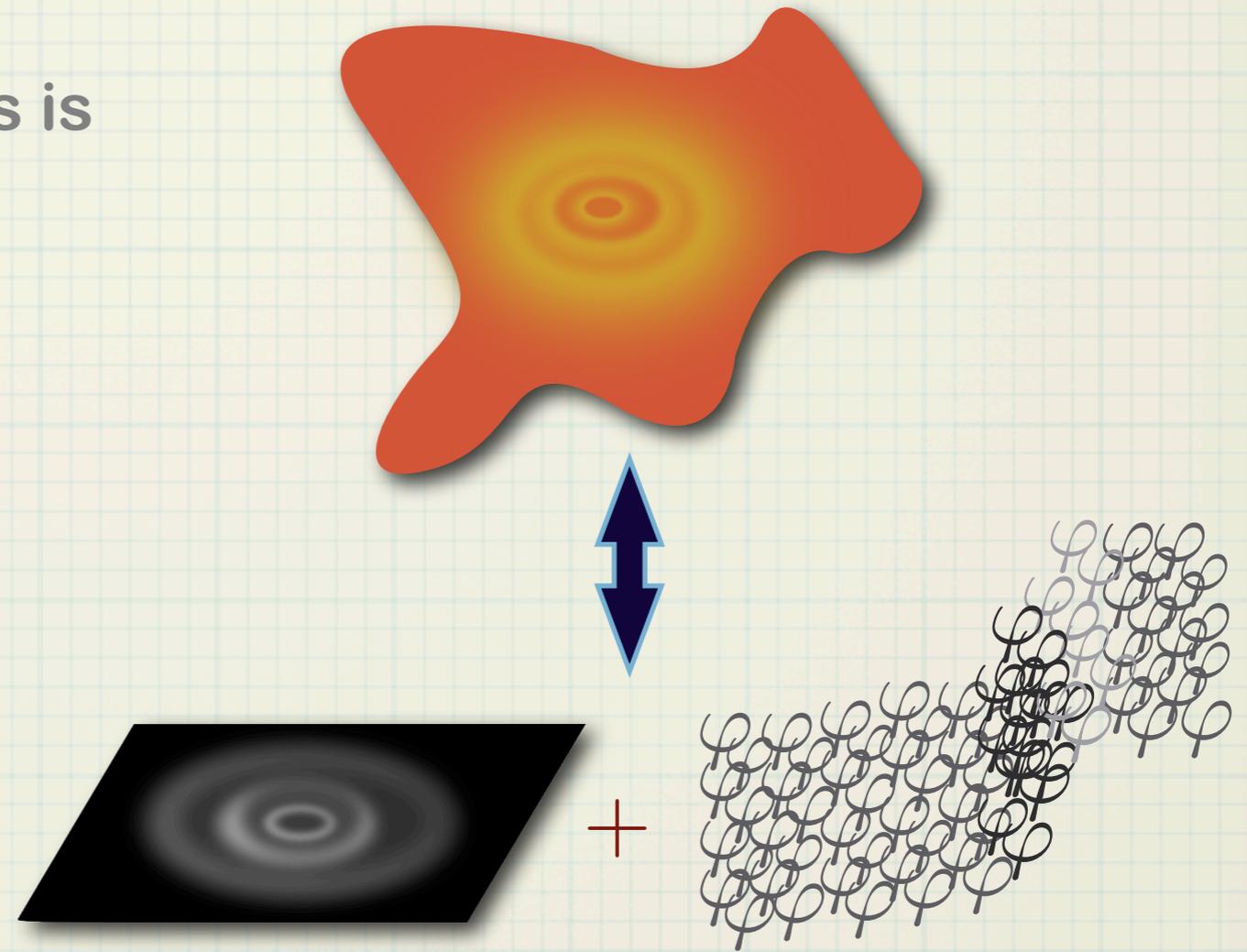


# The (Other) Way Things Work

In absence of universality, emphasis is on 'more QCD-ish' theories

- Breaking conformality allows access to interesting dynamics:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = T_{\mu\nu}$$



# The (Other) Way Things Work

In absence of universality, emphasis is on 'more QCD-ish' theories

- Breaking conformality allows access to interesting dynamics:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = T_{\mu\nu}$$

- In a conformal plasma, speed of sound is fixed by constraint on stress-energy tensor:

conservation of dilatation current makes tensor traceless...

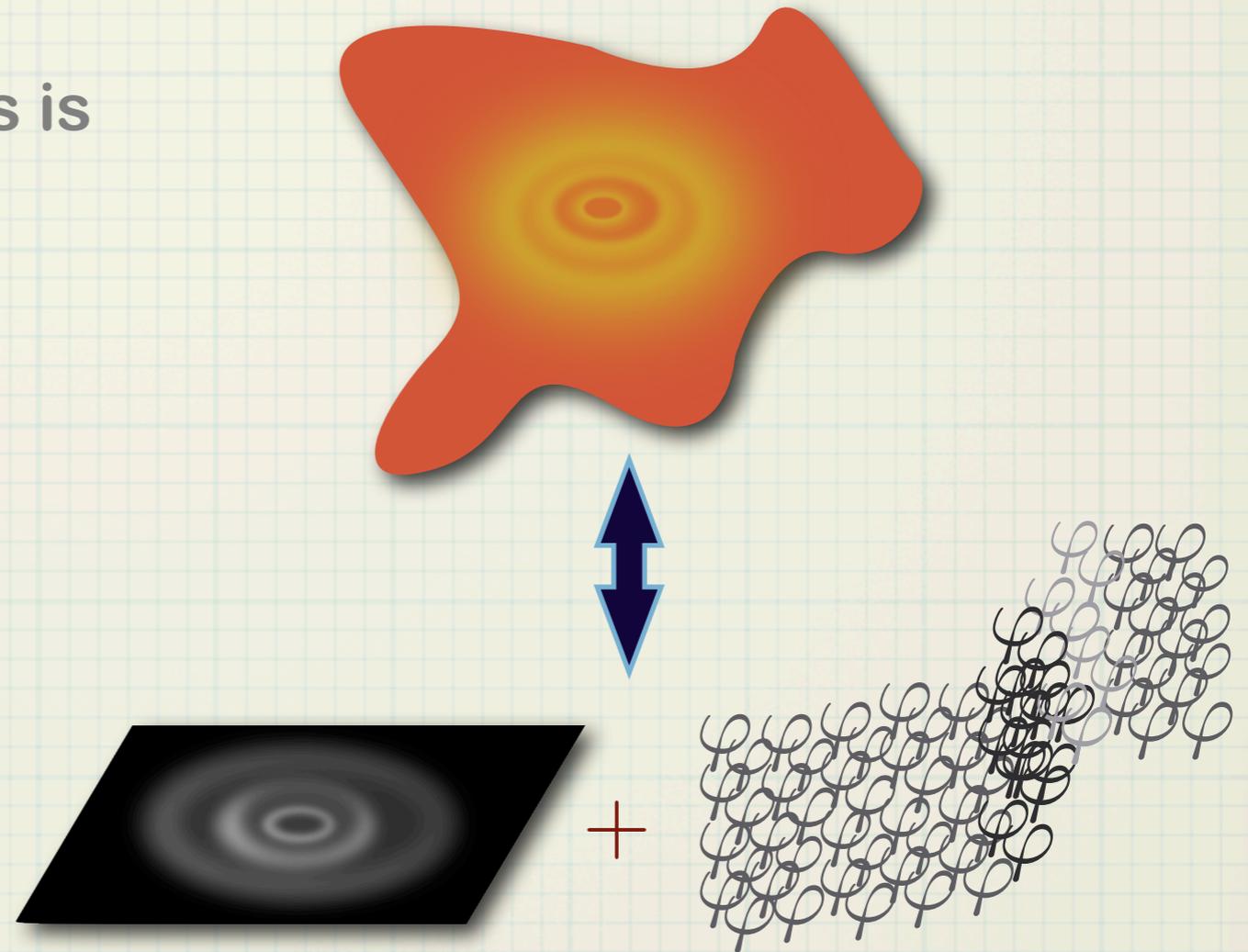
$$j^\mu = x_\nu T^{\mu\nu} \quad \text{so} \quad \partial_\mu j^\mu = T^\mu{}_\mu = 0$$

then

$$\epsilon = 3P$$

and

$$c_s^2 = \frac{\partial P}{\partial \epsilon} = \frac{1}{3}$$



# The Example

Conformality test serves as convenient diagnostic

- From general results, investigate speed of sound, etc.  
(S. Gubser et al, arxiv:0806.0407v1 [hep-ph])

For

$$ds^2 = \frac{R^2 e^{\hat{c}z^2}}{z^2} \left[ - \left( 1 - \frac{z^4}{z_0^4} \right) dt^2 + d\vec{x}^2 + \left( 1 - \frac{z^4}{z_0^4} \right)^{-1} dz^2 \right]$$

find

$$c_s^2 \approx \frac{1}{3} \left[ 1 - \frac{1}{\left( 1 - \frac{\pi^2 T^2}{\hat{c}} \right)^2} \right]$$



- While potentially useful, could benefit from more judicious choice of test metric.

# The Take Home Message(s)

String theorists are working hard to model the QGP, get things right

- AdS/CFT offers framework for developing controlled approximations to QCD physics.
- If not universal, hope for results that are 'robust' to non-conformality and 'infrared sensitive'.
- Breaking conformal invariance allows access to more relevant hydrodynamic quantities.

